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CRACK DEPTH AND CRACK LOCATION IDENTIFICATION USING ARTIFICIAL NEURAL NETWORK

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ABSTRACT

Identification of crack depth and crack location is an area of concern for researchers across the globe. In the present paper, artificial neural network used to identify crack depth and crack location. Finite element model of rotary shaft with two bearing support was generated. A single crack of varying depth (2mm, 4mm and 6mm) was provided to finite element model of a shaft. Crack distance from bearing support was altered (100 mm, 200 mm, 300 mm and 400 mm). Natural frequency of rotor shaftwas obtained using the modal analysis method. Critical speed of shaft models was obtained from Campbell diagram. Thus, natural frequency and critical speed for all variations of cracks depth and crack locations were obtained. Critical speed and natural frequency for known crack location and crack depth wereused to train an artificial neural network. The training of artificial neural network was completed, with the help of artificial neural network crack location, and crack depth was identified accurately.

KEYWORDS: Crack Detection, Crack Identification, Modal Analysis & Artificial Neural Network

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Original Article

1. INTRODUCTION

It is important to find out a crack location and crack depth accurately in the rotary shaft, to avoid catastrophic failure. Identification of crack location and crack depth also helps in preventive maintenance activity. Anuj Kumar Jain et al. observed effect of position of crack location on stiffness of shaft [1]. M. J. Gómez, C. Castejón and J. C. García-Prada combined wavelet packet transform with artificial neural network to detect crack in rotary shaft [2]. M. J. Gómez, C. Castejón and J.C. García-Prada carried out wavelet packet transform energy analysis for identification of crack in shaft. It was observed that as the crack grows, wavelet packet transform energy rises [3]. Mohamed. R. et al. Observed change in vibration signal for different stages of crack propagation [4]. V. Sudheer Kumara et al. observed displacement curve by varying crack location distance from bearing support. It was found that, if a crack was near to bearing support, there was maximum displacement. If a crack location was away from bearing support, less displacement was observed [5]. K. Vigneshwaran and R.K. Behera observed that the location of crack can be identified with help of variation in mode shapes. It was also observed that due to the variation of crack location, there was a change of natural frequency of vibration [6]. Alok Ranjan Biswal et al. developed a finite element model of a beam with crack, using Timoshenko beam theory. It was observed that the amplitude of vibration varies with respect to crack depth [7]. Sandeep Das et al. used Adaptive Nero Fuzzy Interface System (ANFIS) to identify crack location & crack depth. It was found that ANFIS

finds crack location and crack depth more accurately compared to FEM and theoretical method [8]. M.J. Gómez, et al. developed the crack detection technique, using wavelet packet transform energy. This technique is useful for condition monitoring at stationary condition [9]. T. Sunil Kumar et al. carried out frequency response analysis of composite beam. This process provides a non-destructive method for identification of crack depth and location[10]. K.M. Saridakis et al. identified cracks in shaft, using an artificial neural network, genetic algorithm and fuzzy logic [11]. Sachin K. Singh and Rajiv Tiwari identified crack depth and crack location in shaft using slope discontinuity in elastic line of shaft [12]. José Fernández-Sáez et al. carried out single crack detection in a simply supported beam with help of natural frequencies [13]. Hamid Khorrami et al. developed an analytical model of a shaft with two cracks to observe the effect of the presence of the second crack on the dynamic behaviour of the system [14]. Chaozhong Guo et al. used FFT analyser to check variation in amplitude of vibration. With the help of amplitude variation, crack detection was carried out [15]. Debabrata Gayen, et al. observed dynamic properties as natural frequency and critical speed, by varying crack size [16]. D.Koteswara Rao modelled functionally graded shaft using Timoshenko beam theory. It was observed that functionally graded shaft was suitable for rotating shaft than conventional shaft [17]. Gayen D, Chakraborty D. and Tiwari R. Modelled functionally graded shaft with transverse crack and observed an effect of crack depth on natural frequency and critical speed [18]. Ghanbari Mardasi et al. carried out crack detection using wavelet packet transform and experimentally [19]. A. P. Stawiarski used wave propagation method for detection and localisation of fatigue crack [20]. Tejas Aher et al. observed that as crack depth increases, natural frequency of vibration decreases. Crack location can be identified with help of a change in natural frequency [21]. D.I.Sampio and R.Nicoletti found that crack depth more than 5% can be detected with help of approximate entropy method [22]. A.P. Bovsunovsky developed a new procedure of vibration-based damage detection. Crack in shaft identified using variation in shaft compliance [23]. A. P. Stawiarski carried out a comparative study of all damage detection technique and proposed a simple analytical damage detection technique using change in shaft compliance due to the presence of crack [24]. J. Xiang et al. observed natural frequency of vibration of a shaft for various crack sizes. A genetic algorithm was used to remove error between analytical natural frequency and practical natural frequency of shaft [25]. In present paper, Finite element approach was used to obtain critical speed and frequency of vibration.

2. METHODOLOGY

- A 88o mm long shaft was modelled using CATIA V5 software. A single crack of length 1mm and different crack depths (2mm, 4mm, 6mm) were generated in a modelled shaft. As shown in figure 1, crack was provided on the shaft at distance of 100mm, 200mm, 300mm and 400mm, from bearing 2 supports.

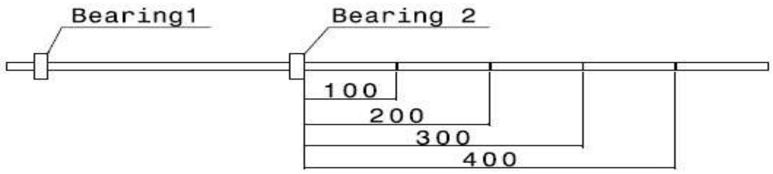


Figure 1: Crack Locations

- For each crack, location crack depth of 2 mm, 4 mm and 6 mm was provided to the shaft models. As shown in table 1, for one crack location, there were three crack depths. With a combination of four crack locations, and three crack depths, 12 models of shaft were generated using CATIA V5 modelling software.

Table 1: Different Crack Location and Crack Depth

Crack Location from Bearing 2 (mm)	Crack Depth Provided on Shaft(mm)		
100	2	4	6
200	2	4	6
300	2	4	6
400	2	4	6

- These models were imported to Ansys 16 analysis software. Material properties are assigned to these models.
- Campbell diagram for every shaft model was drawn. From the Campbell diagram, we will get critical speed of the shaft model. At critical speed, shaft vibrates with maximum amplitude.
- Modal analysis of each shaft model was carried out using Ansys 16 software. From modal analysis, natural frequency of vibration of shaft was obtained.
- For every shaft model, critical speed and natural frequency were obtained using Ansys 16. This data was used to train an artificial neural network.
- Once the training of artificial neural network is over, critical speed and natural frequency of shaft were given as input to ANN, and the ANN would give crack location and crack depth as output.

3. FINITE ELEMENT METHOD

Finite element method includes the following steps. Section 3.1 describes modelling of the shaft. Section 3.2 discusses about material properties assigned to shaft model. Section 3.3 describes the procedure of mesh generation. In section 3.4, the boundary condition for FEA analysis is discussed.

3.1 Modelling of Shaft

Modelling of shaft with combination of four crack location and three crack depths are done on CATIA V5. Totally, 13 models of shafts are prepared. One shaft is modelled with no crack. Analysis of all shafts was carried out using Ansys 16.

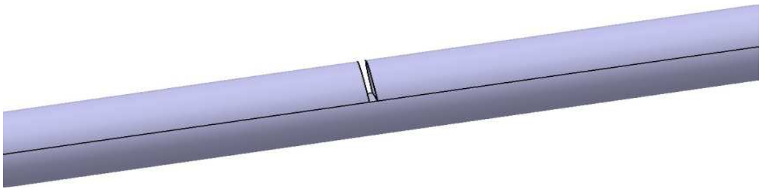


Figure 2: Modelling Shaft with Crack

3.2 Material Properties

The material for shaft was Steel 304. The material properties of steel 304 are as follows.

Table 2: Material Properties of Shaft

Material	Density	Young's Modulus	Poison's ratio
Steel 304	8000Kg/m3	193E+09	0.29

3.3 Mesh Generation

The solid model was imported to Ansys 16. Tetrahedron mesh was generated for the same. Figure 3 shows the meshed shaft model. The size of mesh element was 0.03mm. The bearing outer case was fixed in all degrees of freedom. The number of elements created were 1, 65,238.

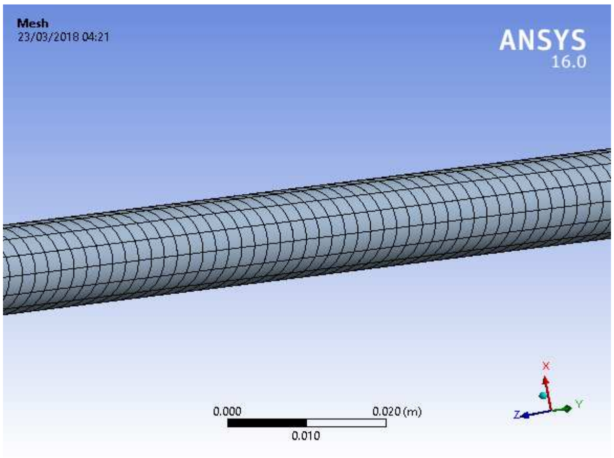


Figure 3: Meshing of Shaft

3.4 Boundary Condition

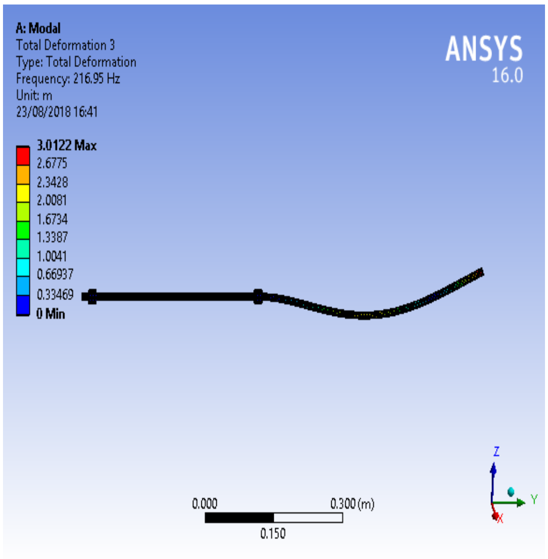
The meshed shaft model is supported in bearing. All degree of freedom of bearings were fixed. Two types of analysis were performed on shaft model i.e. modal analysis and Campbell diagram. Model analysis gives the natural frequency of vibration of the rotor shaft. Campbell diagram shows a critical speed of the rotor shaft.

4. RESULTS AND DISCUSSIONS

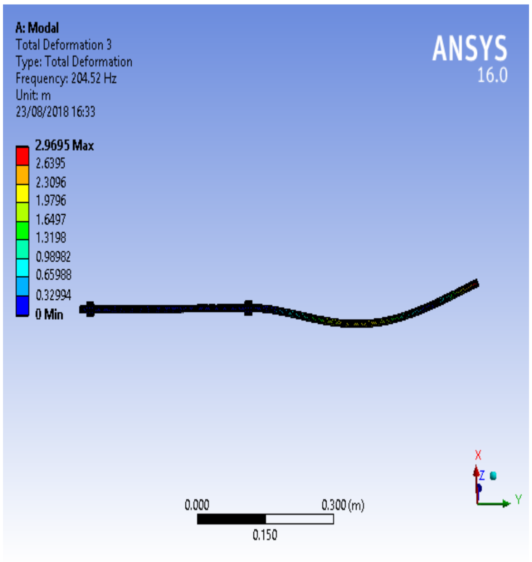
In section 4.1, the results obtained from modal analysis are discussed. Section 4.2 describes Campbell diagrams obtained from finite element analysis. Section 4.3 describes critical speed and natural frequency results obtained for different crack depths and crack locations.

4.1. Modal analysis

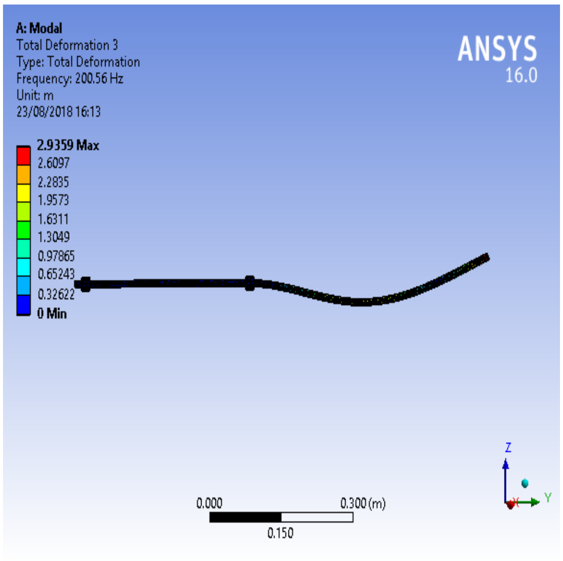
Model analysis is free vibration testing of shaft models. Natural frequency of vibration of shaft bearing system was obtained from this analysis. In the present analysis, we have considered third natural frequency of vibration. Mode shapes for third natural frequency of vibration can be seen in figure 4(a, b, c, d).



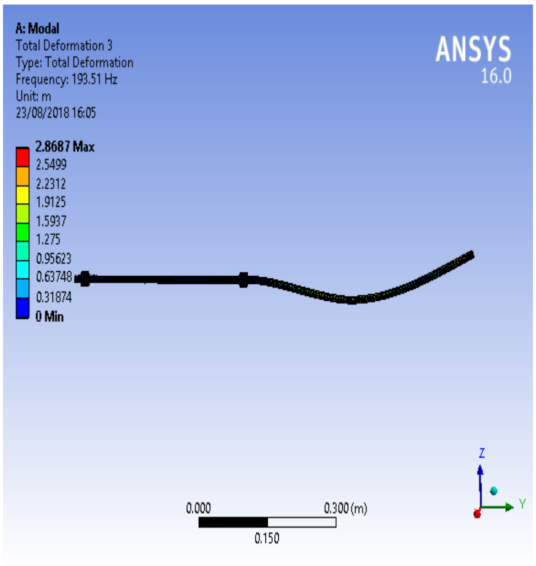
a) Modal Analysis of Shaft with no Crack



b) Modal Analysis of Shaft with Crack Depth 2mm



c) Modal Analysis of Shaft with Crack Depth 4mm

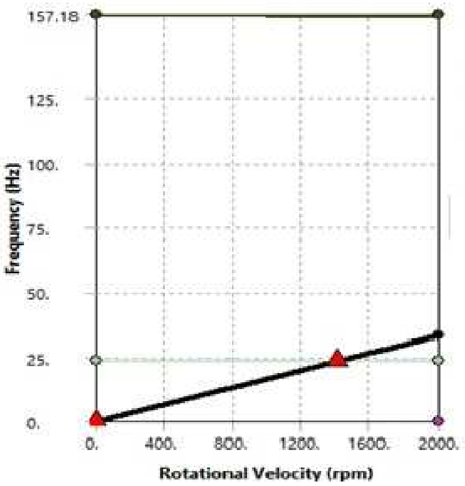


d) Modal Analysis of Shaft with Crack Depth 4mm

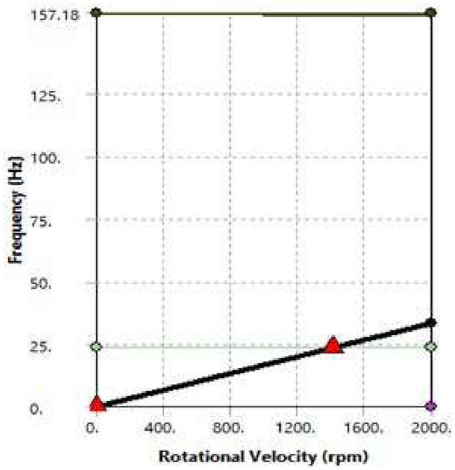
Figure 4: Modal Analysis of Shafts

4.2. Campbell Diagram

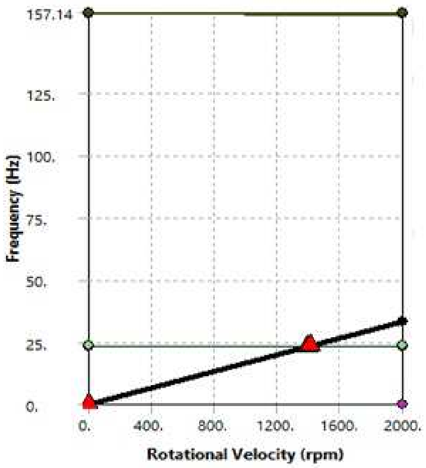
Campbell diagram is a graph of the speed of rotary shaft in rpm versus natural frequency of vibration of the rotary shaft in Hz. Red point on Campbell diagram represents critical speed of rotation and natural frequency of vibration of shaft at resonance. Figure 5(a, b, c, d) shows Campbell diagram for shaft, with no crack and crack depth 2mm, 4mm and 6mm. Campbell diagram was obtained using ANSYS 16.



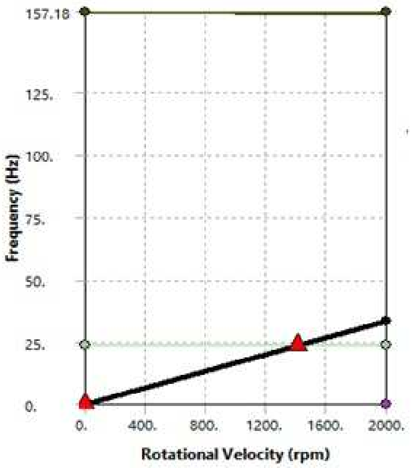
a) Without Crack



b) Crack Depth 2mm



Crack Depth 4mm



Crack Depth 6mm

Figure 5: Campbell Diagram Rotational Velocity Vs Frequency of Vibration

4.3 Result Table

Table 3 represents the critical speed and frequency of vibration for different crack depth and crack location. From result table, variation of the critical speed of shaft with respect to crack depth and crack location can be observed. Also, variation of a frequency of vibration of the shaft, with respect to crack depth and crack location was observed from the result table.

Table 3: Critical Speed and Frequency of Vibration of Shaft

Location of Crack from Bearing 2. (mm)	Crack Depth (mm)	Critical Speed (RPM)	Frequency of Vibration (Hz)
Without crack	---	1410	216.95
100	2	1370	204.52
	4	1352	200.56
	6	1308	193.51
200	2	1363	197.20
	4	1324	192.36
	6	1296	187.63

300	2	1351	189.17
	4	1311	184.65
	6	1280	178.32
400	2	1338	184.23
	4	1302	177.13
	6	1263	169.74

5. ARTIFICIAL NEURAL NETWORK

The neural network works in two-phase learning phase and operation phase. As shown in figure 6, it takes input as critical speed and natural frequency of vibration and forms an input matrix. An artificial neural network takes crack location and depth of crack as output, and form the target matrix. Feedforward neural network was formed, which was trained for given input and output. As neural network training completes, it gives output for new inputs with very high accuracy. Table 4 represents the input and output of an artificial neural network. Input for ANN was critical speed and frequency of vibration, and it gives crack location and crack depth as output.

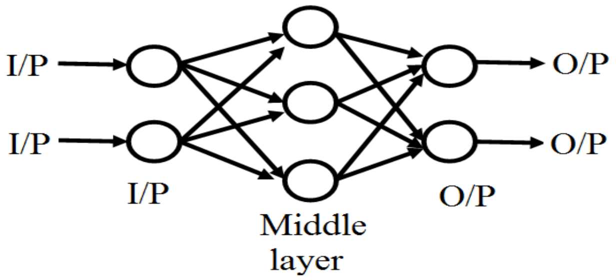


Figure 6: Structure of Artificial Neural Network

Table 4: Crack Location and Crack Depth Obtained Using Artificial Neural NETWORK

Inputs to ANN		Output from ANN	
Critical Speed in RPM	**Frequency of Vibration In Hz**	**Crack Distance from Bearing 2**	**Crack depth**
1370	204.52	100	2mm
1352	200.56	100	4mm
1308	193.51	100	6mm
1363	197.20	200	2mm
1324	192.36	200	4mm
1296	187.63	200	6mm
1351	189.17	300	2mm
1311	184.65	300	4mm
1280	178.32	300	6mm
1338	184.23	400	2mm
1302	177.13	400	4mm
1263	169.74	400	6mm

6. CONCLUSIONS

In this experiment, shaft model with different crack location and crack depths were prepared. Modal analysis of all shaft models was performed, to find the frequency of vibration. Campbell diagram for all shaft models was generated to find the critical speed of shafts. Critical speed and natural frequency of vibration of shaft were obtained for different crack depth and crack locations. It was observed that as the depth of crack increases, critical speed and frequency of vibration decreases. As the crack distance from bearing support increases, critical speed and frequency of vibration decreases.

An artificial neural network was trained by using critical speed and natural frequency data for known crack depth and crack location. After training ANN, it identified the crack depth and crack location accurately, for the given critical speed and natural frequency.

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